Digital Image Processing for Fuel Inspection Automation

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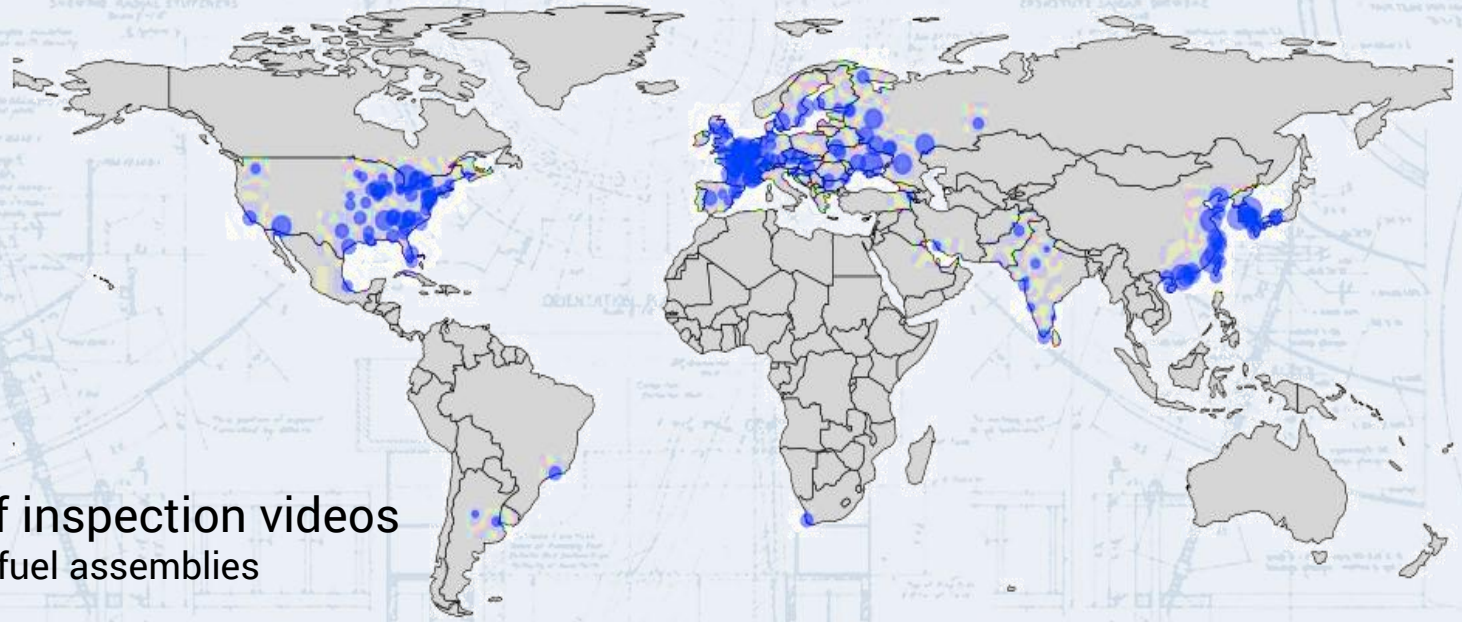
Digital Image Processing services for nuclear fuel inspection

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Track Record

- CVR has performed fuel inspections since 2011
- Cooperation with square-fuel vendors since 2023
- Implementation of new inspection equipment and ideas



Multiple NPPs
International outage inspections

Thousands of inspection videos
Real operational fuel assemblies

Routine outage experience
Multiple fuel campaigns

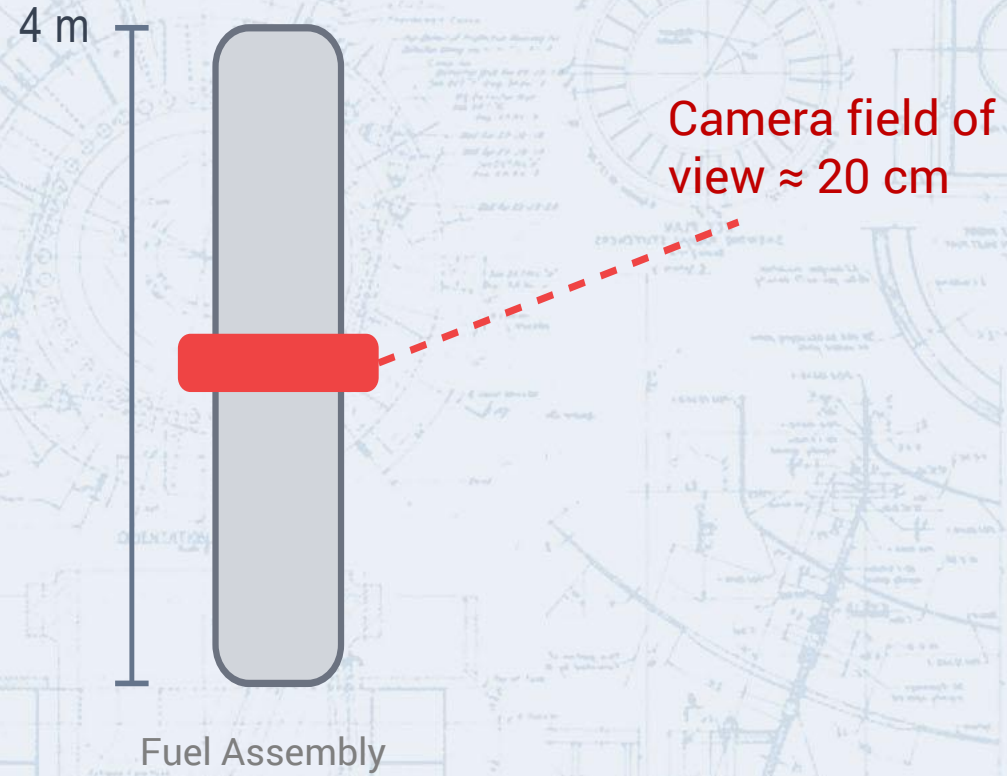
PWR & VVER expertise
Inspection → quantitative data

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The inspection challenge

The camera sees the fuel.
The engineer has to understand it.



Continous inspection

- Live video during outage
- Radiation environment
- Large amount of data

Human bottleneck

- Concentration
- Repetitive review
- Interpretation

Engineering challenge

- Extract reliable information
- Identify anomalies
- Compare the inspection data

The challenge is not recording the video—it is extracting reliable engineering information from it.

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Why Conventional Inspection Has Limited Value

Digitalization converts inspection videos into standardized engineering knowledge.

TODAY

- Only selected fuel assemblies are inspected
- One inspection after each operating campaign
- Manual expert interpretation
- Isolated inspection reports
- Difficult historical comparison

DIGITALIZED

- Searchable engineering datasets
- Standardized measurements
- Repeatable evaluation
- Lifetime FA history
- Foundation for predictive analytics

Value for the plant

- Safety assurance
- Fuel performance data
- Regulatory compliance
- Reduced operational risk
- Lower engineering workload

More data | **Less repetitive work** | **Better decision**

Digital Inspection Workflow

One inspection – one digital workflow

1 Acquisition



Inspection videos
+ metadata

2 Processing



Detection
Tracking
Gemoetry connection
Stitching

3 OIO



Spatial
representation

4 Engineering data



Measurements
Features
Annomalies

5 Reporting & database



Standardized
outputs
Searchable records

6 Trend analysis



Cycle-to-cycle
comparison

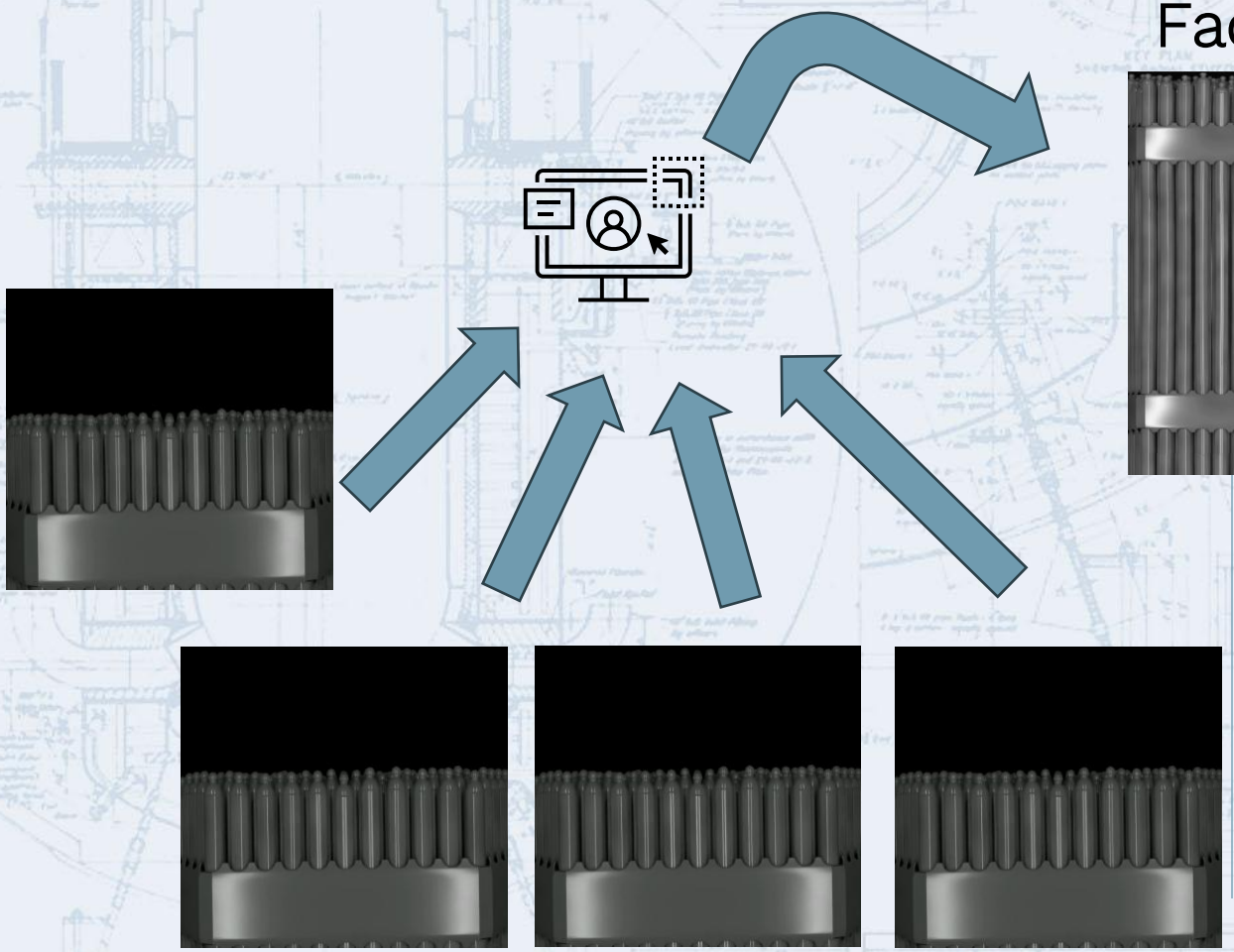
Video → Information → Knowledge

Synthetic data creation

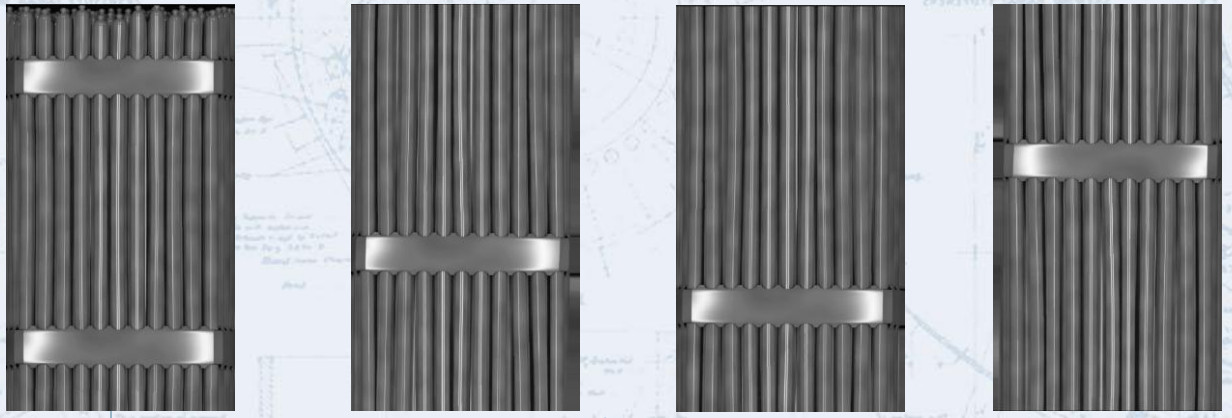
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One Image Overview – the key part of SW



Face 1 Face 2 Face 3 Face 4



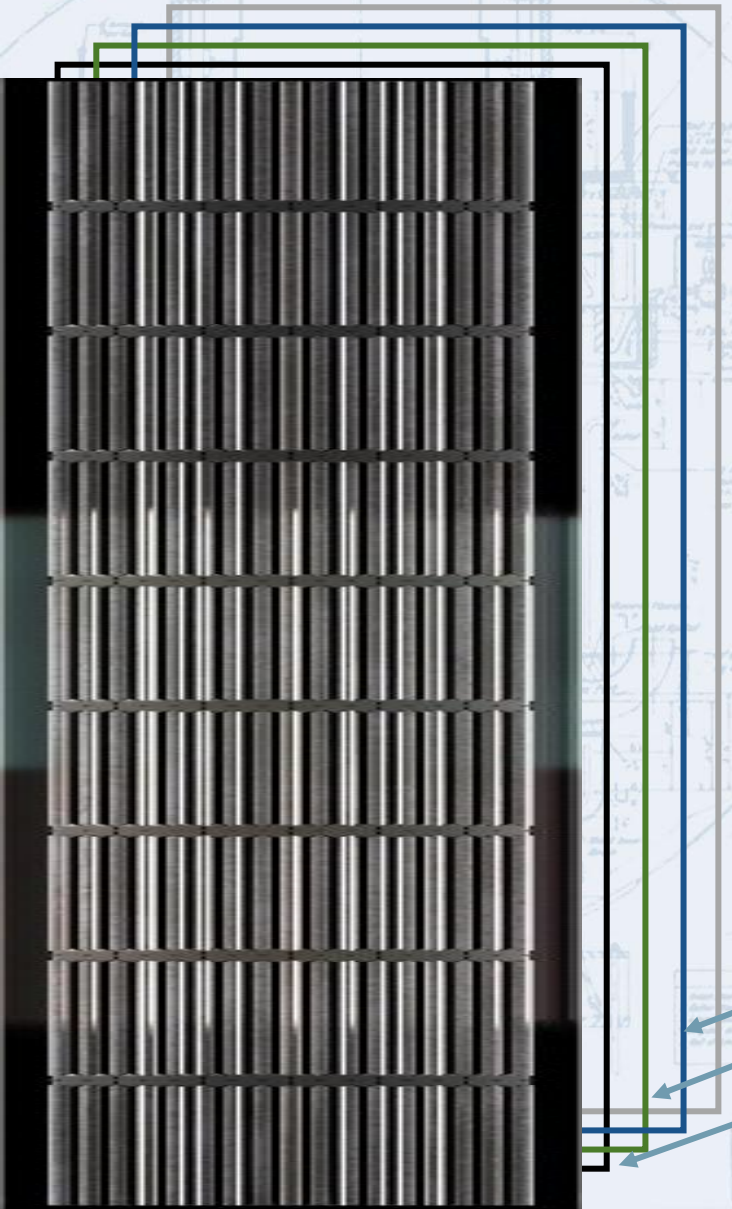
- ✓ Full spatial context
- ✓ Fast overview
- ✓ Zoomable
- ✓ Effective comparison
- ✓ Easy reference
- ✓ Annotation & GUI
- ✓ No context loss

OIO converts thousands of video frames into one spatial engineering view

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How OIO is created



Detect Rod → Track Position → Correct Geometry → Stitch OIO

1. Detection
AI identifies individual fuel rods.

2. Tracking
Continuous position estimation through video.

3. Geometry
Perspective and optical distortion removed.

4. Stitching
Frames merged into one spatially consistent OIO.

MIO – Matrix of Image Overview

- FA BOW
- FR BOW
- FR Growth
- Anomalies
- ...

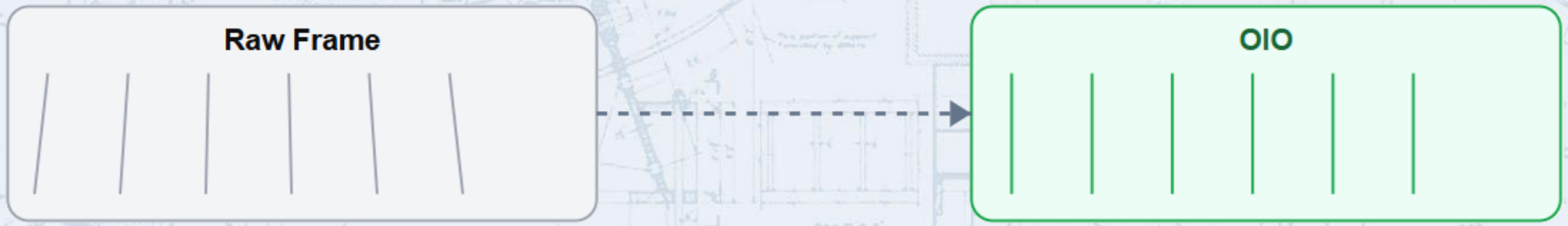
Engineering Output Quality

Engineering-grade documentation, not visual enhancement.

Resolution
Fine surface features

Geometry
Perspective corrected

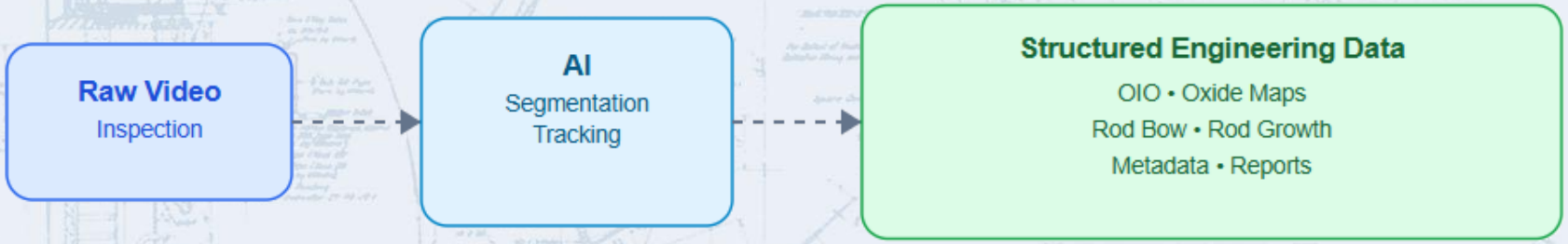
Repeatability
Identical input = identical output



OIO = image + geometry + inspection context

Value for the plant

More data flow. Less workload. Better decisions



Before

- Video recordings
- Manual notes
- Individual measurements
- Separate reports

After

- Standardized datasets
- Automatic measurements
- Searchable database
- Consistent engineering reports

Digitalization converts inspection videos into standardized engineering knowledge.

Value for the Utility

Operational • Knowledge • Economic

Operational

Lower engineering workload
Faster outage reporting
Better maintenance planning

Knowledge

Standardized FA history
Searchable inspection database
Lifetime trend analysis

Economic

Lower OPEX
Reduced repetitive work
Digital Twin readines

Digitalization generates value on three levels simultaneously: operational efficiency, engineering knowledge, and long-term economic benefit.

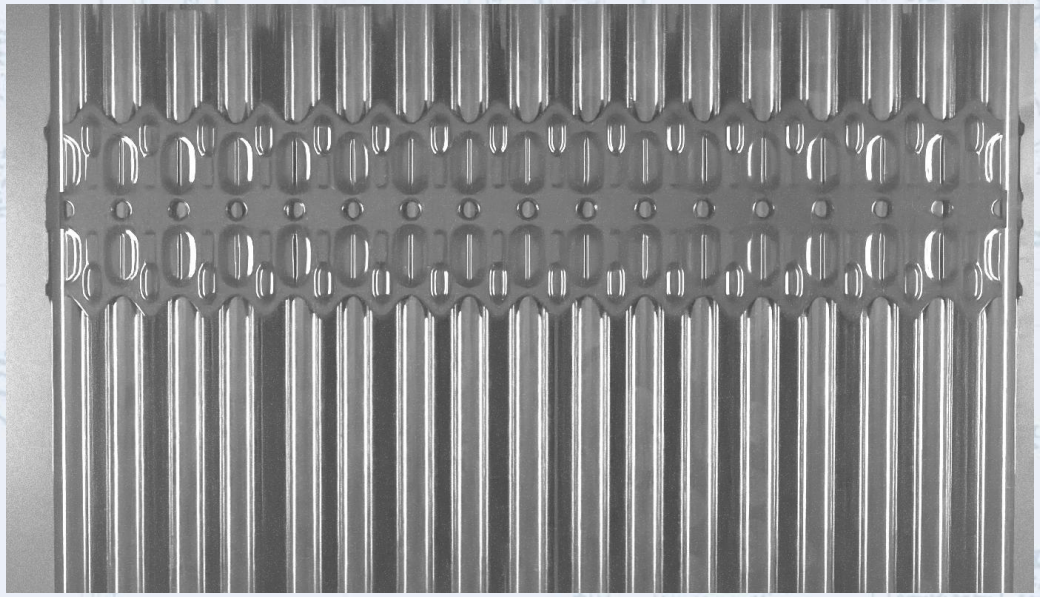
Value for the Utility

Synthetic Nuclear Fuel Inspection

→ The crew training.

Photorealistic rendered picture

- enable sharing/publishing without releasing sensitive information
- increase variability of data to improve AI models



Oxide layer

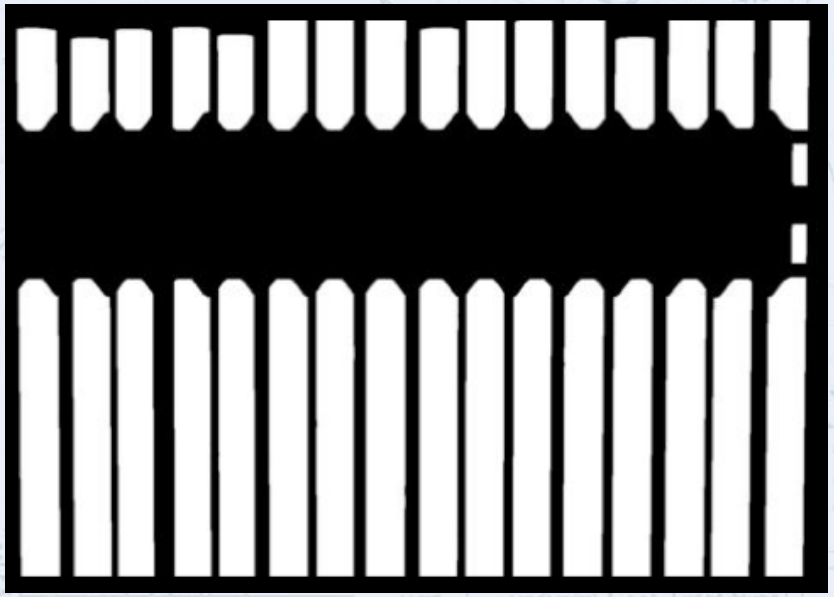
Simulation based on blackbox optimization



- 4face/6face
- different grid types
- variable NFA length or spacer grid distances
- fuel bow

Labeling

- Synthetic frames are ready for AI application
- Labels are rendered along with the data:



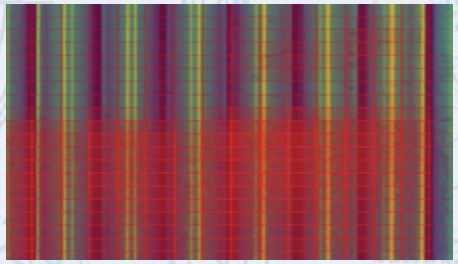
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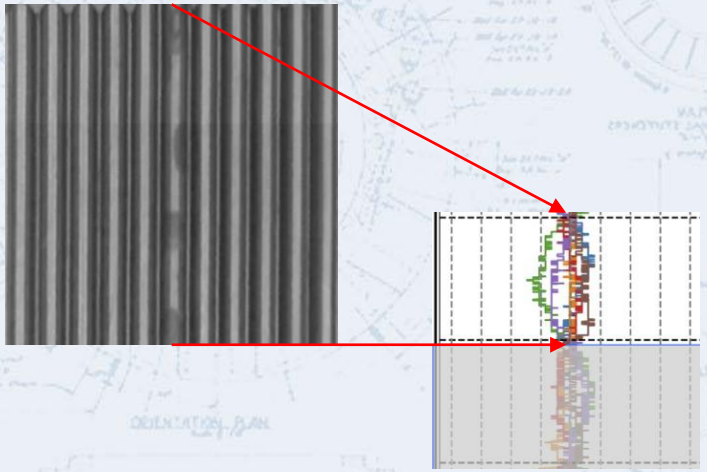
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Chráněné / Protected

From Visualization to Engineering Data

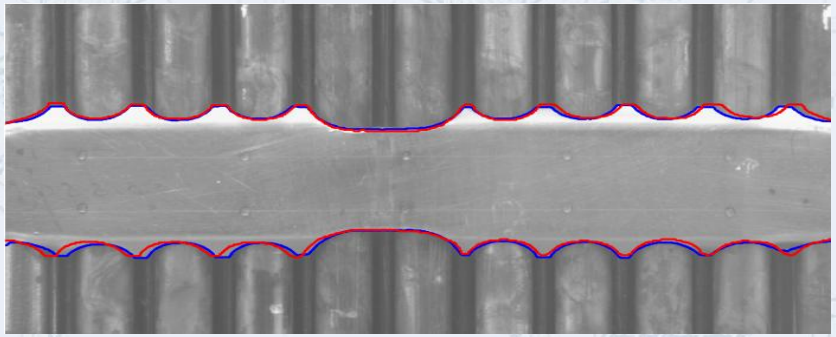
OIO enables quantitative engineering analysis





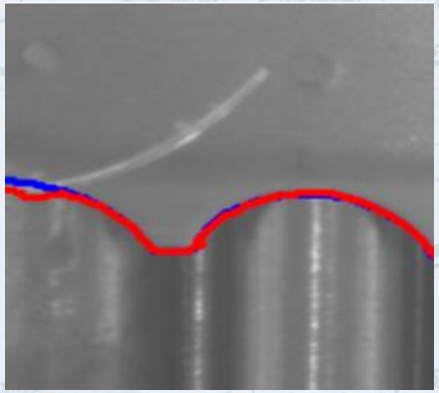
BASIC:

- Fuel geometry
- Rod geometry
- Rod surface
- Whatever unusual
- Reports



EXTENSION:

- Foreign objects recognition
- Automatic video cut
- Rod growth measurement
- Oxidation map
- Skeleton growth
- Segmentation
  - Oxides
  - Spacer grids
- Reports/charts/previews



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Standardized FA history

Every new inspection extends the digital lifetime record of the fuel assembly.

Instead of isolated inspections, utilities obtain a comparable digital history for every monitored FA across multiple campaigns.

1

Cycle 1
- Oxide map
- Rod bow
- Rod growth
- Metadata
- Same coordinate system

2

Cycle 2
- Oxide map
- Rod bow
- Rod growth
- Metadata
- Same coordinate system

3

Cycle 3
- Oxide map
- Rod bow
- Rod growth
- Metadata
- Same coordinate system

4

Cycle 4
- Oxide map
- Rod bow
- Rod growth
- Metadata
- Same coordinate system

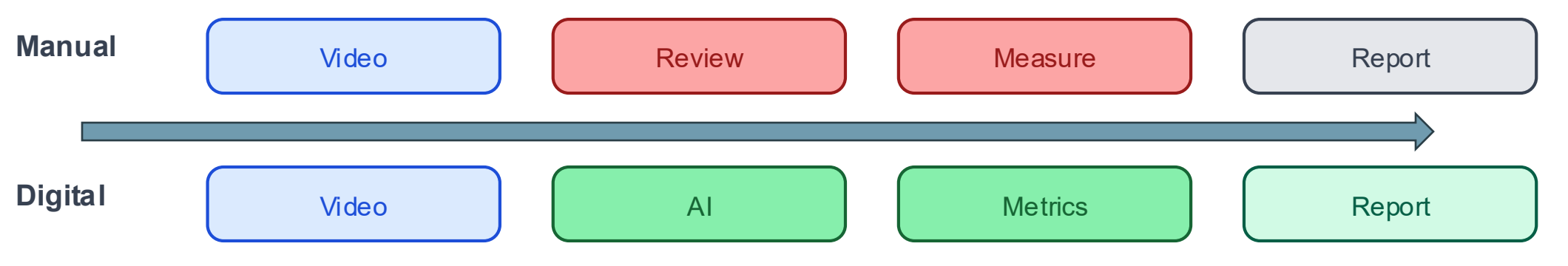
Without digitalization

- Independent inspection reports
- Different measurement methods
- Limited comparison

With standardized OIO

- Continuous FA history
- Same coordinate system
- Lifetime trend analysis

Time savings during outage



60-90%
less engineering review

Shorter outage
Earlier reload decision

Data context
Faster fuel disposition

Business value

From inspection videos to strategic operational knowledge.

Operational

Higher Availability
- Faster outage decisions, lower engineering workload

Knowledge Retention
- Unified inspection database

Regulatory Confidence
- Traceable & reproducible evidence

Virtual fuel
- Knowledge throughout the team and generations

Economic

Lower OPEX
- Reduced manual analysis and reporting

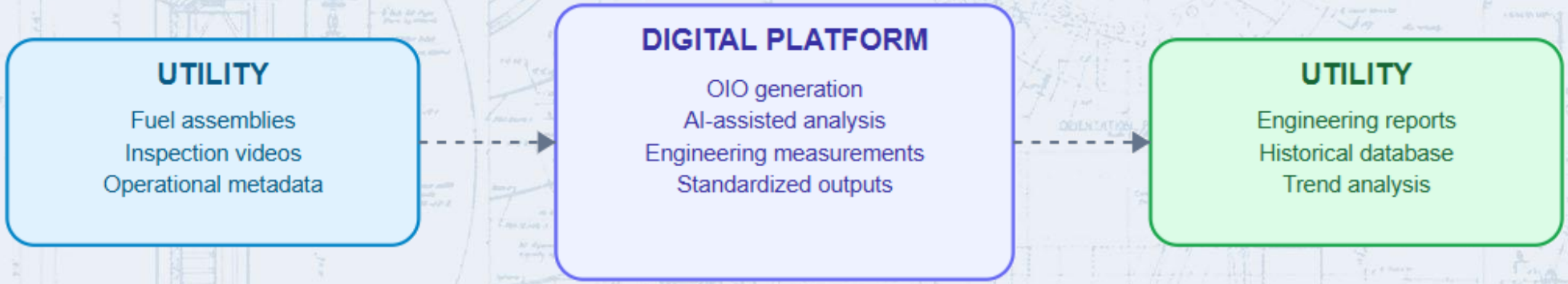
Better Fuel Management
- Trend-based evaluation

Expert training data
- Virtual datasets for fuel experts' training

Future Digital Twin
- Structured datasets for predictive models

Cooperation Model

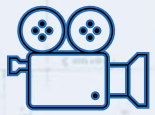
A secure digital service for nuclear utilities



Principles

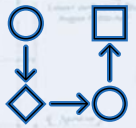
- Utility remains the owner of all inspection data.
- Processing can be performed on-site/offline and remotely.
- Outputs integrate with existing engineering workflows.

Executive summary



Inspection videos become standardized engineering data

Every frame contributes to quantitative, traceable information.



OIO creates comparable lifetime records for every fuel assembly

Standardization enables true historical analysis across operating campaigns.



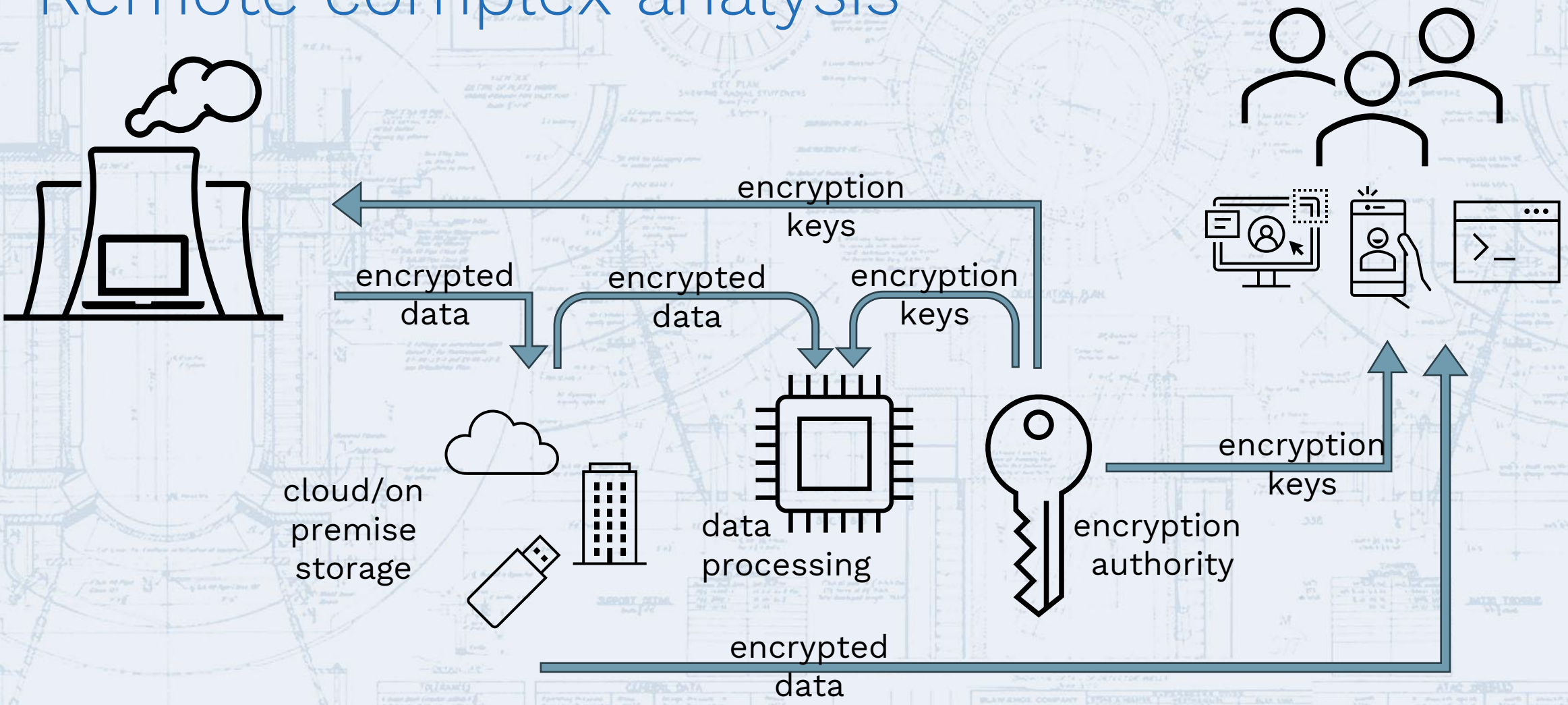
60–90% reduction of engineering review effort

Earlier outage decisions improve availability and reduce engineering workload.

From inspection videos to strategic operational knowledge.

A standardized digital inspection platform provides the foundation for safer operation, long-term fuel intelligence, and future Digital Twin implementation.

Remote complex analysis



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Thank you!

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